Characterization of TOMATO VARIETIES AND STRAINS For Constituents of Fruit Quality

A. E. Thompson, R. W. Hepler,
R. L. Lower, and J. P. McCollum

Bulletin 685

UNIVERSITY OF ILLINOIS AGRICULTURAL EXPERIMENT STATION

CONTENTS

Urbana, Illinois April, 1962

Publications in the Bulletin series report the results of investigations made or sponsored by the Experiment Station

Characterization of Tomato Varieties and Strains for Constituents of Fruit Quality

A. E. Thompson, R. W. Hepler, R. L. Lower, and J. P. McCollum[1]

Very limited improvement of tomato fruit quality can be accomplished by selection based upon visual observation. For this reason research has been conducted at the Illinois Agricultural Experiment Station since 1945 on the development of rapid, objective breeding methods and techniques for the measurement and identification of fruit quality factors (1, 3, 6, 7, 8, 9, 10, 11, 12).[2] The need for such research has been accentuated by the rapid development of the mechanical tomato harvester.

Such factors as resistance to cracking, firmness of flesh, and ability to withstand handling, take on increased importance in view of the impending technological changes. The ability of a variety to hold ripened fruit on the plant for a long period of time so that higher yields can be obtained in a once-over harvest is also important.

However, as fruits ripen, the pH generally increases and the total titratable acidity decreases. Such decreases in acidity undoubtedly will increase the loss of processed products through spoilage, commonly called "flat sour." Such spoilage is caused by the germination of certain thermophyllic bacterial spores not killed by the heating process or not held in check by an adequate level of acidity. Therefore, higher levels of acidity than are normally found in tomato varieties would be highly desirable. Higher levels of citric acid, which constitute a large portion of the titratable acidity in the tomato fruit, may necessitate a proportional increase in sugars to balance the flavor of the fruits and processed products.

Color is considered one of the most important characteristics of tomato fruit quality. The inadequacy of selection by visual methods becomes apparent when it is realized that color depends upon both the content of total carotenoids and the ratio of lycopene to carotene. Genetic variation in tomato fruit color is known to exist, but the separation of heritable from environmental effects is extremely difficult unless adequate sampling and testing techniques are employed.

McCollum (11) thoroughly discussed the problem of sampling tomato fruits for composition studies. He pointed out that where the constituents of quality are dependent upon so many factors such as maturity, light

---

[1] This bulletin was prepared by A. E. Thompson, Associate Professor of Vegetable Crops; R. L. Lower, Research Assistant in Vegetable Crops; and J. P. McCollum, Professor of Vegetable Crops, all of the Department of Horticulture; and R. W. Hepler, formerly Assistant Professor of Vegetable Crops, Department of Horticulture, and now Geneticist, California Packing Corporation, San Leandro, California.

[2] Numbers in parentheses refer to literature cited.

exposure and accompanying temperatures, morphological structure, position on the plant, and season of development, differences between progenies or treatments are difficult to measure without the utmost care in sampling.

Before an effective breeding program can be initiated for any characteristic, it is always desirable to determine the nature and extent of variation existing in available varieties and breeding lines. Widely scattered references regarding measurement of some of the constituents of fruit quality on certain varieties or strains are available in the literature. Assembling these data for comparative purposes, however, would be of little value since the environmental conditions under which the plants were grown would vary greatly, and the sampling and measurement methods would not be adequate in most instances.

The primary objectives of this study were to measure under comparable conditions the various constituents of fruit quality on a selected collection of standard varieties and breeding lines or strains, and to demonstrate the feasibility of utilizing available techniques in a practical plant breeding program. This was to be accomplished by using the most appropriate methods of analysis and measurement, and a standardized procedure of sampling. The data collected would help define the extent of variability and thereby characterize the various varieties and lines as possible sources for future tomato breeding research. The utilization of these data and the adoption of these techniques by plant breeders would have the effect of placing the improvement of the tomato on a firm scientific basis.

MATERIALS AND METHODS

An attempt was made to assemble and evaluate varieties and breeding lines upon which selection had been practiced with regard to the constituents of fruit quality. A total of 21 were selected for inclusion in the replicated experiment. Table 1 lists the source of seed, and Table 2 lists the reasons individual varieties or strains were included.

The plants were set in the field at the Vegetable Crops Research Farm at Urbana on May 24, 1961, by means of a single-row transplanter. The experimental design was a randomized complete block with two replications, and plots of 30 plants. The large number of plants per plot was used to assure the selection of a uniform sample. The spacing was 5 feet between and 3 feet within the rows. Standard fertility, cultural, and disease and insect control practices were followed. Table 3 gives a summary of the temperatures and rainfall for the 1961 growing season. The temperature averaged approximately 2 degrees below and the rainfall approximately 2 inches above the 1903-1954 mean for this period of time at Urbana.

Table 1. — Varieties and Strains Tested and Source of Seed

Variety or strain	Date received	Pedigree number, if any	Number of generations selfed and selected at Illinois	Source of seed
1252	....	(Y 13 X Garden State[3]) F_7	...	Ill. Agr. Exp. Sta., Urbana
1483	....	(Acc. 326 X Garden State[3]) F_6	...	Ill. Agr. Exp. Sta., Urbana
Garden State	1944	......	17	Campbell Soup Co., Riverton, N. J.
Y 13	1953	Y 13-MDS2	8	Campbell Soup Co., West Chicago, Ill.
Y 112	1956	Y 112-MFS2	5	Campbell Soup Co., West Chicago, Ill.
Y 206	1956	Y 206-MCS1	5	Campbell Soup Co., West Chicago, Ill.
Kc 109	1957	Kc 109-J10	6	Campbell Soup Co., Riverton, N. J.
Kc 146	1957	Kc 146-E19	6	Campbell Soup Co., Riverton, N. J.
HRS 193	1960	HRS 193-8-2-2-C	2	W. Shumovich, Ont. Agr. Res. Sta., Harrow, Ont. Canada
Imp. T-2	1960	......	1	Peto Seed Co., Saticoy, Calif.
T 6003	1960	T 6003	1	L. Butler, Univ. of Toronto, Canada
Ark. 60-19-1	1961	60-19-1	0	J. McFerran, Ark. Agr. Exp. Sta., Fayetteville
Rutgers	1961	......	0	Purdue Alumni Seed Imp. Assoc., Lafayette, Ind.
Roma	1961	......	0	Joseph Harris Co., Inc., Rochester, N. Y.
Gardener	1961	54-179 (Lot 59-23)	0	H. M. Munger, N.Y. Agr. Exp. Sta., Ithaca
NY 59-400	1961	59-400	0	H. M. Munger, N. Y. Agr. Exp. Sta., Ithaca
H 1369	1961	H 1369	0	H. J. Heinz Co., Bowling Green, Ohio
ES 24	1961	Eastern States 24	0	H. J. Heinz Co., Bowling Green, Ohio
Ace-VF	1961	......	0	Alpha Seeds, Lompoc, Calif.
Brehm's Solid Red	1961	91522, V 982-1	0	Eastern States Farmers' Exchange, W. Springfield, Mass.
MAT	1961	MAT-D6130	0	Ferry Morse Seed Co., Rochester, Mich.

Table 2. — Reasons for Inclusion of Varieties or Strains in Experiment

Variety or strain	Control variety	Fruit characteristics: Color	Crack resistance	Firmness	pH and acidity	Total solids	Notes
1252		X		X			High pigment(*hp*)
1483					X		High acid line
Garden State	X						
Y 13		X		X			High pigment (*hp*)
Y 112						X	
Y 206						X	
Kc 109			X				
Kc 146	X		X				
HRS 193		X	X	X			"Crimson" color
Imp. T-2	X						CPC-2 type (California Packing Corp.)
T 6003		X					"Crimson" color?
Ark. 60-19-1		X					"Dark red" color from *Lycopersicon pimpinellfolium*
Rutgers	X						
Roma	X		X				Paste type fruit
Gardener				X			Soft fruit
NY 59-400			X	X			
H 1369			X	X			
ES 24			X	X			
Ace-VF	X						
Brehm's Solid Red			X	X			
MAT	X	X					Dark green immature fruit color similar to high pigment, but not *hp hp*

Table 3. — Temperatures and Rainfall During the Growing Season of 1961 at the Vegetable Crops Research Farm, Urbana

Date	Temperature, °F.: Maximum	Minimum	Mean	Precipitation for week (in.)
May 21 through May 27	68	38	53	.5
May 28 through June 3	77	53	65	.1
June 4 through June 10	82	59	71	5.9
June 11 through June 17	75	56	66	T
June 18 through June 24	77	52	64	2.1
June 25 through July 1	87	58	73	.0
July 2 through July 8	80	58	69	.8
July 9 through July 15	83	58	71	T
July 16 through July 22	83	66	74	1.2
July 23 through July 29	84	65	75	2.2
July 30 through Aug. 5	85	69	77	2.0
Aug. 6 through Aug. 12	82	63	73	.0
Aug. 13 through Aug. 19	86	58	72	T
Aug. 20 through Aug. 26	75	56	66	T
Aug. 27 through Sept. 2	87	65	76	.0
Sept. 3 through Sept. 9	88	66	77	.0
Sept. 10 through Sept. 16	80	57	68	1.4
Season total	..	..	..	16.2
Season mean	81	59	70	...
Weekly mean	..	..	..	.95

The plots were sampled by selecting uniformly shaded fruits at incipient color, or at the so-called "turning stage." The samples were placed in an air-conditioned ripening chamber, the temperature of which was maintained at 65° ± 1.5° F. Samples were ripened for both 7 and 14 days before analysis. Measurements were made on each sample for color, firmness, pH, total titratable acidity, total solids, soluble solids, and weight of fruits. Measurements of resistance to cracking were also made, but on a separate sample.

When the experiment was designed, it was thought that one replication could be analyzed for the various quality factors during a single day. Therefore, two days would be necessary to complete a given sampling date. The field plots were sampled at two separate dates — August 15 and 16, and August 29 and 30, 1961. Fruits of the first date were analyzed after only 7 days of ripening. The second sampling was ripened and analyzed after both 7 and 14 days.

The samples were handled and analyzed in the following manner. A minimum of 10 fruits per sample was weighed and a median section, one-half inch thick was cut from each fruit. The slices to be tested were placed on a flat plexiglass plate of a model of the Illinois Firmness Tester originally described by Foda (3) and by Garrett *et al.* (4). A plastic container was placed on a plunger with a diameter of one-half inch, which was then placed in position on the tomato slice. The weight of the plunger and empty container was 314 grams. Care was taken to center the plunger on homogeneous inner wall tissue free from concentrations of vascular elements.

The solenoid valve was opened by activating a mercury switch which allowed water to flow from a reservoir into the container. The mercury switch automatically shuts off the flow of water when the combined weight of the water, container, and plunger fully compresses (punctures) the flesh of the slice. The container was calibrated to read the weight of the water to 0.1 of a pound. Data were expressed in pounds of water necessary to compress the sample, and the larger the value the firmer the flesh of the fruit. These data can readily be converted to pounds per square inch by applying the formula $\frac{x + .69}{.19635}$. The variety Roma was not tested for firmness. Fruits of this variety are generally two-loculed and the inner wall tissue of the fruits are not thick enough to test with the one-half inch plunger.

After testing for firmness the whole fruit samples were blended for 2 minutes in a one-gallon Waring Blendor. A sample of approximately 500 ml. of the blended juice was taken for further analyses after having been strained through a doubled layer of cheesecloth to remove skins and seeds.

Measurements of total carotenoids and carotene were made using the spectrophotometric method of McCollum (8). Percent transmittance of the total carotenoid and carotene samples were both read at 450 mμ on a Bausch and Lomb Spectronic 20 colorimeter. Total carotenoid extracts of the 14-day samples were cut 1:1 with pure hexane before they were read. Transmittance data were converted to milligrams per 100 grams fresh weight. The ratios of total carotenoids to carotene (T/C) were calculated as a numerical expression of visual color. Color readings were made with a Hunter Color and Color Difference Meter using the large aperature and large area illumination with the Campbell standard ($R_d = 6.9$, $a = 34.9$, $b = 16.6$) and recorded as a/b ratios. Hunter readings on the first sampling date were not obtained due to a malfunction of the instrument.

The pH and total acidity were measured on a Beckman automatic titrator. Readings were made on 10-gram samples of tomato juice to which 90 ml. distilled water had been added. Titrations were made with 0.1N NaOH to an end point pH of 8.1. Total titratable acidity was expressed as grams of citric acid per 100 grams fresh weight.

Total solids were determined by drying 20-gram samples of juice for 24 hours to a constant weight in a drying oven at 80° C. Soluble solids were measured with a Bausch and Lomb hand refractometer on samples prepared by straining a drop of juice through four layers of cheesecloth.

Samples to be tested for resistance to cracking were selected on September 18, 1961. Ten fruits at incipient color were harvested from each plot. All fruits were tested by the vacuum-immersion method of Hepler (6). Fruits were evacuated at seven inches of mercury and immersed in water maintained at 20° C. for 3 hours. The cracks on individual fruits were then classified as radial or concentric and measured in centimeters with a map measure. The total length of both types of cracks was also recorded. The raw data were transformed to the square root of $x + \frac{1}{2}$ before being analyzed statistically.

The data were analyzed statistically by means of the analysis of variance method. In all instances, except for fruit cracking, three separate analyses were calculated. They are as follows: (1) the comparison of the two 7-day samples; (2) the comparison of the 7- and 14-day samples harvested at the same date; and (3) the analysis of the 14-day samples. Since data for the first sampling date were not available for the Hunter a/b readings, the analysis of variance of the 7-day samples of the second date was calculated. The accidental loss of the 14-day sample of the variety Brehm's Solid Red necessitated the calculation of a missing subplot value.

An orthogonal breakdown of the degrees of freedom for varieties was made for the three measurements of cracking and for firmness. The indi-

vidual comparisons were made on the basis of the classification of the varieties as listed in Table 2. At the time the experiment was designed, grouping varieties into specific color classes was not considered feasible since sufficient knowledge of the basis for some of the color differences was not available. Therefore, no breakdown was computed for the measurements of fruit color. Since only one or two varieties were previously classified as sources of the other characters, no individual comparisons were made. In all instances, the means of the 7 + 7- and the 14-day samples were ranked and the shortest significant ranges were calculated by means of Duncan's "Multiple Range Test" (2, 5).

Additional studies of an exploratory nature were conducted on a portion of the varieties and strains with regard to the holding capacity of fruits on a plant, and the resistance of fruits to breakage when dropped. To determine the holding capacity, fruits at incipient coloring of eight varieties with varying levels of firmness and resistance to cracking were tagged on August 24, 1961. Tagged fruits were harvested two weeks later. Fruits were counted, weighed, and graded into marketable and cull classifications. Four types of defects on the culls were recorded. Those fruits decayed beyond recognition of the causal factor were classified as total decay. The other defects were sunburn, decay at cracks, and ground rot.

To determine the nature of the variables involved in the resistance of fruits to breakage, a series of samples was tested. Factors studied were height of drop and the number of times dropped at a given height to induce cracking, stage of maturity, size of fruit, time of day, moisture content and temperature of fruits, and varietal differences. In most tests, the standard, crack-resistant variety Kc 146 was used. The variety Kc 109 was used in the study on the effect of fruit size since a wider range in size was available in this line. Ten varieties or strains from the replicated experiment were tested to determine the extent of variation among varieties. In addition, fruits of a line homozygous for the gene sticky peel (*pe*), which was reported by Hepler (6) to be highly resistant or immune to cracking, was tested.

In all instances unless otherwise indicated, the fruits were dropped on the stylar end on a hard surface. The effect of dropping fruits of the variety Roma on both the stylar end and the side was tested. To study the effect of moisture content and temperature in fruits, samples were infiltrated with cool and warm water at 21° and 35° C. respectively. Infiltration was accomplished in the vacuum-immersion crack resistance tester at 5 inches of mercury. Evacuation was continued until air bubbles ceased coming from the samples. In some instances, data were taken on fruit weight, total carotenoid pigments, and firmness on samples comparable to those tested for breakage.

DISCUSSION OF RESULTS

Four measurements of fruit color — total pigment, carotene, ratio of total pigment to carotene (T/C), and Hunter a/b ratios

In all instances, highly significant differences were measured among the 21 varieties or strains tested for the four measurements of fruit color (Table 4). There was no significant difference between the means of the two 7-day samples, but highly significant differences were measured between the 7- and 14-day samples. In general, total pigments, T/C and a/b ratios increased in magnitude, but carotene decreased with ripening from the 7th to the 14th day after incipient coloring (Tables 5, 6, 7, and 8). In only one instance was there any indication of a differential re-

Table 4. — Analysis of Variance of 21 Varieties and Strains Tested for Measurements of Fruit Color at Different Sampling and Testing Dates

Source of variation	Degrees of freedom	Mean squares for — Total pigments	Carotene	Ratio of total pigment to carotene (T/C)	Hunter[1] a/b
7 + 7-day samples					
Total	83				
Replications	1	8.8855	.0309	.13	.0013
Sampling dates	1	12.6675	.0051	239.71	....
Error a	1	9.5209	.0053	39.09	....
Varieties	20	3.9128**	.0391**	84.24**	.0577**
Error b	20	1.0837	.0052	7.79	.0098
Varieties x sampling dates	20	.7942	.0074	9.27	....
Error c	20	.5808	.0047	12.94	....
7 + 14-day samples					
Total	82[2]				
Replications	1	15.1470**	.0324**	6.30	.0039
Varieties	20	7.1194**	.0335**	132.44**	.0959**
Error a	20	1.1491	.0034	14.96	.0090
Testing dates	1	57.2220**	.0408**	1315.35**	3.6333**
Varieties x testing dates	20	.4712	.0083*	17.83	.0092
Error b	20[2]	.8058	.0037	9.42	.0061
14-day samples					
Total	40[2]				
Replications	1	1.4747*	.0062	.38	.0152
Varieties	20	4.0209**	.0093**	94.16**	.0473**
Error	19[2]	.2759	.0016	13.75	.0049

[1] No 7-day samples for first sampling date.
[2] One degree of freedom less because of missing subplot value.
* Exceeds .05 level of significance.
** Exceeds .01 level of significance.

Table 5. — Ranked Varietal Means of Total Carotenoid Pigments and Shortest Significant Ranges for Two Samplings Harvested at Incipient Coloring and Ripened for 7 Days, and for One Sampling Harvested and Ripened for 14 Days at 65° F.

7+7-day samples			14-day samples		
Variety or strain	Mean (mgm./100gm.)	Shortest significant ranges[1]	Variety or strain	Mean (mgm./100gm.)	Shortest significant ranges[1]
†1252	7.73	a	†1252	11.12	a
†Y 13	7.28	ab	†Y 13	9.58	b
†HRS 193	6.45	abc	†Ark. 60-19-1	9.22	bc
†Ark. 60-19-1	6.01	abcd	†HRS 193	8.42	bcd
1483	5.71	bcd	1483	8.20	cde
NY 59-400	5.64	bcd	NY 59-400	7.86	def
Garden State	5.57	bcd	Rutgers	7.76	defg
†T 6003	5.45	cd	Garden State	7.60	defgh
Gardener	5.36	cde	†T 6003	7.31	defghi
Kc 109	5.28	cde	Gardener	7.26	defghi
Rutgers	5.06	cde	Roma	7.00	efghi
Y 206	4.96	cde	MAT	6.80	fghij
Y 112	4.92	cde	Kc 146	6.65	fghijk
Brehm's Solid Red	4.79	cde	Kc109	6.61	fghijk
Roma	4.76	cde	Ace-VF	6.58	fghijk
Ace-VF	4.72	cde	Y 206	6.48	ghijk
Kc 146	4.46	de	H 1369	6.39	hijk
MAT	4.36	de	ES 24	6.10	ijk
H 1369	4.35	de	Brehm's Solid Red	5.66	jk
ES 24	4.24	de	Imp. T-2	5.54	jk
Imp. T-2	3.64	e	Y 112	5.42	k
Mean and standard error	5.27 ± 0.520			7.31 ± 0.371	

[1] Means with the same letter are not different from each other at the .05 level of significance.
† Varieties or strains classified as having fruits with improved red color.

sponse of varieties at different sampling or testing dates — carotene at 7 and 14 days. Carotene content is known to be subject to considerable variation, so such an interaction was not unexpected. It would appear that a satisfactory evaluation of the potential of a variety for development of fruit color can be obtained at one sampling date after either 7 or 14 days of ripening. It is obvious that maximum color has not developed at 7 days, but differences in magnitude normally expressed at 14 days are also sufficient for separation at the earlier stage of ripeness.

Four of the five varieties classified as having superior red color ranked at the top in total carotenoid pigments. The two high-pigment lines 1252 and Y 13 were also higher than those of the other varieties. The line 1252 tended to be superior to Y 13 in color. Foliage cover on Y 13 is rather sparse, and fruits were exposed to higher light intensity before sampling. The effect of illumination of fruits prior to the turning stage

has been previously studied by McCollum (9). Higher light intensity during fruit maturation increases total carotenoid production, but the proportional increase in carotene is higher than that of lycopene. The higher carotene content had an adverse effect on the T/C ratio, especially in the Y 13 line. The total quantity of pigment present apparently influences the Hunter a/b ratio since the line 1252 ranked at the top in the a/b readings even though the T/C ratio was lower. The present results substantiate the findings of Thompson (12) where purees made from high pigment tomatoes had higher Hunter a/b readings than those made from normal tomatoes, but the T/C ratios were lower. It may be concluded that Hunter readings alone are not sufficient for the determination of basic color differences.

The line T 6003 was represented as having the "crimson" color, but it is doubtful if it has this character as typified by HRS 193. The nature of inheritance of this character has not as yet been established. The charac-

Table 6. — Ranked Varietal Means of Carotene and Shortest Significant Ranges for Two Samplings Harvested at Incipient Coloring and Ripened for 7 Days, and for One Sampling Harvested and Ripened for 14 Days at 65°F.

7+7-day samples			14-day samples		
Variety or strain	Mean (mgm./ 100gm.)	Shortest significant ranges[1]	Variety or strain	Mean (mgm./ 100gm.)	Shortest significant ranges[1]
†Y 13	.625	a	†Y 13	.450	a
†1252	.510	ab	†1252	.355	ab
ES 24	.470	bc	ES 24	.355	ab
Garden State	.408	bcd	H 1369	.355	ab
H 1369	.395	bcde	MAT	.355	ab
†T 6003	.352	cdef	Kc 146	.350	bc
Gardener	.352	cdef	Imp. T-2	.330	bcd
1483	.348	cdef	1483	.315	bcd
Kc 109	.332	defg	Rutgers	.305	bcde
†Ark. 60-19-1	.328	defg	Garden State	.300	bcde
MAT	.325	defg	†T 6003	.290	bcde
Kc 146	.322	defg	Gardener	.290	bcde
Ace-VF	.312	defgh	†HRS 193	.265	bcdef
Brehm's Solid Red	.302	defgh	†Ark. 60-19-1	.260	bcdef
†HRS 193	.295	defgh	Ace-VF	.255	cdef
Imp. T-2	.288	defgh	Y 206	.255	cdef
Y 206	.282	defgh	Y 112	.235	def
Rutgers	.280	efgh	Kc 109	.210	ef
Y 112	.248	fgh	Roma	.190	f
Roma	.212	gh	NY 59-400	.190	f
NY 59-400	.195	h	Brehm's Solid Red	.185	f
Mean and standard error	.342±0.0361			.290±0.0283	

[1] Means with the same letter are not different from each other at the .05 level of significance.
† Varieties or strains classified as having fruits with improved red color.

Table 7. — Ranked Varietal Means of the Ratio of Total Pigment to Carotene (T/C) and Shortest Significant Ranges for Two Samplings Harvested at Incipient Coloring and Ripened for 7 Days, and for One Sampling Harvested and Ripened for 14 Days at 65° F.

7+7-day samples			14-day samples		
Variety or strain	Mean	Shortest significant ranges[1]	Variety or strain	Mean	Shortest significant ranges[1]
NY 59-400	28.92	a	NY 59-400	42.75	a
Roma	24.62	ab	Roma	36.90	ab
†HRS 193	22.18	bc	†Ark. 60-19-1	36.15	ab
Y 112	20.55	bcd	Kc 109	31.90	bc
†Ark. 60-19-1	19.42	cde	†HRS 193	31.80	bc
Rutgers	18.50	cdef	†1252	31.40	bc
Y 206	18.02	cdefg	Brehm's Solid Red	26.40	cd
1483	16.78	defgh	1483	26.00	cde
Kc 109	16.12	defgh	†T 6003	25.90	cde
Brehm's Solid Red	16.12	defgh	Ace-VF	25.75	cde
†T 6003	15.92	defgh	Garden State	25.40	cde
Ace-VF	15.42	efghi	Rutgers	25.40	cde
Gardener	15.35	efghi	Y 206	25.40	cde
†1252	15.10	efghi	Gardener	25.20	cde
Kc 146	14.15	fghi	Y 112	23.05	cde
Garden State	13.92	fghi	†Y 13	21.35	de
MAT	13.45	ghij	Kc 146	19.25	de
Imp. T-2	12.75	hij	MAT	19.15	de
†Y 13	12.22	hij	H 1369	18.15	de
H 1369	11.12	ij	ES 24	17.35	de
ES 24	9.25	j	Imp. T-2	16.95	e
Mean and standard error	16.66 ± 1.396			26.27 ± 2.622	

[1] Means with the same letter are not different from each other at the .05 level of significance.
† Varieties or strains classified as having fruits with improved red color.

teristic color of the crimson material appears to be based upon a moderately high level of total pigments and a relatively low level of carotene thus giving favorable T/C and a/b ratios. The lower level of carotene is especially noticeable in the locular region, which generally has a relatively high level. The line Ark. 60-19-1 appears to have similar color characteristics to that of HRS 193. Wann and McFerran (13) postulated the inheritance of color typified by Ark. 60-19-1 to be multigenic. Additional research will be needed to determine what relationship, if any, exists between these two sources of fruit color.

The performance of the varieties NY 59-400 and Roma with respect to color is of interest. Both are very low in carotene and consequently high in T/C and a/b ratios. NY 59-400 also ranks high in total pigments, and appears to have a pigment potential somewhat similar to HRS 193

and Ark. 60-19-1. The Illinois high-acid line 1483, derived from a cross between Garden State and a high-acid selection of PI 163246 (Ill. Acc. 326), also has a rather high potential for production of total pigments, and ranks above average for carotene, T/C and a/b ratios.

Inspection of the means in Tables 5, 6, 7, and 8 clearly indicates a number of varieties that have relatively low potential for production of fruit color. Poor color in most of these lines results from a combination of low total carotenoids and high carotene. The variety MAT, which was included because it had dark green, immature fruit color similar to that found in the high-pigment lines, had a relatively low potential for color. Although high chlorophyll content appears as a pleiotropic effect of the high-pigment gene, there apparently is little association between chlorophyll and total carotenoid pigments in the variety MAT. At the 14-day sampling, the carotene content of the two high-pigment lines, however, was not significantly greater than that of MAT.

Table 8. — Ranked Varietal Means of Hunter a/b and Shortest Significant Ranges for Two Samplings Harvested at Incipient Coloring and Ripened for 7 and 14 Days at 65° F.

7-day samples			14-day samples		
Variety or strain	Mean	Shortest significant ranges[1]	Variety or strain	Mean	Shortest significant ranges[1]
†1252	1.850	a	†1252	2.255	a
NY 59-400	1.815	ab	Roma	2.250	a
†HRS 193	1.745	abc	†HRS 193	2.175	ab
Roma	1.740	abc	NY 59-400	2.150	abc
1483	1.665	abcd	†Ark. 60-19-1	2.050	bcd
Y 206	1.665	abcd	†Y 13	2.015	bcde
Kc 109	1.655	abcd	Ace-VF	2.010	bcde
Y 112	1.645	abcde	1483	2.005	bcde
†Y 13	1.625	abcde	Gardener	2.000	cde
†Ark. 60-19-1	1.605	bcde	Kc 146	1.995	cde
Ace-VF	1.550	cdef	Kc 109	1.985	cde
†T 6003	1.510	cdef	Rutgers	1.985	cde
Gardener	1.485	defg	†T 6003	1.940	def
ES 24	1.480	defg	Garden State	1.920	defg
Kc 146	1.475	defg	Y 112	1.880	defg
Garden State	1.430	defgh	Y 206	1.870	efg
Brehm's Solid Red	1.425	defgh	Brehm's Solid Red	1.865	efgh
Rutgers	1.410	efgh	ES 24	1.795	fgh
MAT	1.360	fgh	MAT	1.755	gh
H 1369	1.250	gh	Imp. T-2	1.755	gh
Imp. T-2	1.240	h	H 1369	1.705	h
Mean and standard error	1.554±0.0700			1.970±0.0495	

[1] Means with the same letter are not different from each other at the .05 level of significance.
† Varieties or strains classified as having fruits with improved red color.

Three measurements of cracking — radial, concentric, and total — by vacuum immersion

Highly significant differences were measured among the 21 varieties tested by the vacuum-immersion method (Table 9). Varieties classified as resistant had highly significantly fewer cracks than those classified as susceptible. Highly significant differences were also measured within both resistant and susceptible groups, except for concentric cracking within the resistant lines where the difference was significant at the 0.05 level. The measurement of concentric cracking is subject to greater error variation than that of radial cracking as indicated by the F test of the error by the sampling error variances. The variation in concentric cracking is also reflected in the error for total cracking. These data fully substantiate the findings of Hepler (6) in this regard.

Table 9. — Analysis of Variance of 21 Varieties or Strains Tested for Resistance to Radial, Concentric, and Total Fruit Cracking

Source of variation	Degrees of freedom		Mean squares for —		
			Radial cracking	Concentric cracking	Total cracking
Total	419				
Replications	1		.46	4.36	1.09
Varieties	20		13.42**	14.95**	21.13**
Resistant vs. susceptible		1	113.45**	45.01**	173.23**
Among resistant		7	6.43**	12.29*	14.25**
Among susceptible		12	9.16**	14.01**	12.47**
Error	20		.74	3.37**	2.19*
Sampling error	378		.63	1.55	1.12

* Exceeds .05 level of significance.
** Exceeds .01 level of significance.

In general those lines classified as resistant tended to exhibit the highest resistance with a few exceptions (Table 10), thus attesting to the progress made in the breeding for resistance to cracking. The strain Ark. 60-19-1, which was not classified as resistant, exhibited a very good level of resistance to radial, concentric, and total cracking. HRS 193 had a very high level of radial crack resistance, but was very susceptible to concentric cracking. Imp. T-2, which was not classified as resistant, performed in a manner similar to HRS 193. Garden State exhibited very high concentric crack resistance, but was very susceptible to radial cracking. Roma gave the best overall performance in the test. The fruit shape of this variety undoubtedly has an important influence on the measured resistance. Of the standard fruit types, NY 59-400 gave the highest over-

Table 10. — Ranked Varietal Means of Radial, Concentric, and Total Fruit Cracking and Shortest Significant Ranges; Length of Cracks in Centimeters per Fruit (X), Transformed to $\sqrt{X + 1/2}$

Radial cracking			Concentric cracking			Total cracking		
Variety or strain	Mean ($\sqrt{R}$)	Shortest significant ranges[1]	Variety or strain	Mean ($\sqrt{C}$)	Shortest significant ranges[1]	Variety or strain	Mean ($\sqrt{T}$)	Shortest significant ranges[1]
Y 112	4.11	a	Rutgers	3.69	a	Rutgers	5.19	a
Ace-VF	4.11	a	†HRS 193	3.55	a	Y 206	5.08	ab
Garden State	4.00	a	Y 206	3.45	a	Y 112	5.03	ab
1252	3.70	b	MAT	3.30	a	MAT	4.99	ab
MAT	3.66	bc	Imp. T-2	3.27	a	Ace-VF	4.87	ab
Y 206	3.65	bc	1252	2.81	b	1252	4.76	b
Rutgers	3.49	c	Y 112	2.73	bc	†HRS 193	4.26	c
Y 13	3.21	d	Gardener	2.55	bcd	Y 13	4.21	c
1483	3.17	d	T 6003	2.49	bcde	Garden State	4.19	c
†Brehm's Solid Red	3.07	de	Y 13	2.45	bcde	Gardener	4.01	cd
Gardener	2.95	e	Ace-VF	2.36	cdef	Imp. T-2	3.95	cd
†ES 24	2.65	f	†H 1369	2.19	def	1483	3.79	de
T 6003	2.58	fg	†Kc 146	2.08	efg	T 6003	3.70	de
†H 1369	2.50	fgh	1483	1.95	fg	†Brehm's Solid Red	3.53	ef
†Kc 146	2.44	gh	†Brehm's Solid Red	1.71	gh	†H 1369	3.47	efg
Ark. 60-19-1	2.31	h	†ES 24	1.69	gh	†Kc 146	3.27	fg
†Kc 109	2.09	i	†Kc 109	1.40	hi	†ES 24	3.19	g
Imp. T-2	2.03	i	†Roma	1.37	hi	†Kc 109	2.46	h
†NY 59-400	1.99	i	Garden State	1.21	ij	Ark. 60-19-1	2.38	h
†HRS 193	1.95	i	†NY 59-400	.99	ij	†NY 59-400	2.13	h
†Roma	1.18	j	Ark. 60-19-1	.84	j	†Roma	1.67	i
Mean of resistant varieties	2.23			1.87			3.00	
Mean of susceptible varieties	3.31			2.55			4.32	
General mean and standard error	2.90±0.0608			2.29±1.298			3.82±1.046	

[1] Means with the same letter are not different from each other at the .05 level of significance.
† Varieties or strains classified as resistant to cracking.

all performance, and along with Kc 109 should serve as a valuable source of resistance to cracking in future breeding research.

The use of the vacuum-immersion method should greatly increase the precision in testing for resistance to cracking. The method minimizes environmental variation and is well adapted for testing performance of individual plants in large populations of segregating material. In this experiment, 420 individual fruits were selectively harvested, marked, evacuated, soaked, and measured in less than an 8-hour day. Four persons were involved with the harvesting and only two with the rest of the operations. Hepler (6) estimates that it should be possible to screen over 1,000 fruits per day if a scoring system is employed rather than actually measuring the lengths of cracks.

Measurement of firmness of flesh

Highly significant differences in firmness of flesh were measured among the 20 varieties tested (Table 11). A large portion of the variance is attributable to the difference between the means of the two groups — firm and soft or normal fleshed varieties. Highly significant variation was also measured among the varietal means within each of the two groups. No significant difference was measured between the means of the two 7-day samplings, but the decrease in firmness following ripening from 7 to 14 days was highly significant. No differential response of varieties at different testing or sampling dates was measured, thus indicating that an adequate evaluation of the firmness of varieties can be obtained at one sampling date after either 7 or 14 days of ripening. Since the magnitude of the differences between firm and soft varieties is greater at seven days (Table 12), more precise separation would be expected at the earlier stage of ripeness.

In general, the varieties classified as being firm tended to exhibit the highest degree of firmness (Table 12). The two high-pigment lines, Y 13 and 1252, tended to have the highest degree of firmness of the varieties tested. The superior performance of Y 13 in comparison with 1252 is of interest, because the characteristic firmness of the flesh of these and other high-pigment lines appears to be completely associated with the high-pigment gene, *hp*. It is not possible at the present time to determine whether this difference is due to modifying genetic factors or to an interaction of environment with the residual genotype of the two lines.

The Illinois high-acid line 1483 exhibited a surprisingly high degree of firmness, testing well within the range of the firm varieties. NY 59-400 and ES 24 also showed considerable merit, and should serve as valuable sources of firmness in future breeding research. The variety Gardener, which was included in this experiment since it was reported to have

Table 11. — Analysis of Variance of 20 Varieties or Strains Tested for Firmness of Flesh of Fruits at Different Sampling and Testing Dates

7+7-day samples			7+14-day samples			14-day samples		
Source of variation	Degrees of freedom	Mean squares	Source of variation	Degrees of freedom	Mean squares	Source of variation	Degrees of freedom	Mean squares
Total	79		Total	78[1]		Total	38[1]	
Replications	1	.0106	Replications	1	.1248	Replications	1	.0011
Sampling dates	1	.7069	Varieties	19	.9675**	Varieties	19	.4774**
Error a	1	.4243	Firm vs. soft	1	8.8091**	Firm vs. soft	1	3.5545**
			Among firm	6	.7937**	Among firm	6	.3570**
Varieties	19	.8554**	Among soft	12	.4010**	Among soft	12	.2811**
Firm vs. soft	1	9.5172**	Error a	19	.0940	Error a	18[1]	.0661
Among firm	6	.5467**						
Among soft	12	.2879**	Testing dates	1	2.7306**			
Error b	19	.0819	Varieties x testing dates	19	.0489			
			Error b	19[1]	.0903			
Varieties x sampling dates	19	.0690						
Error c	19	.0913						

[1] One degree of freedom less because of missing subplot value.
** Exceeds .01 level of significance.

Table 12. — Ranked Varietal Means of Firmness of Flesh of Fruits and Shortest Significant Ranges for Two Samplings Harvested at Incipient Coloring and Ripened for 7 Days, and for One Sampling Harvested and Ripened for 14 Days at 65° F.

7+7-day samples			14-day samples		
Variety or strain	Mean (lb.)	Shortest significant ranges[1]	Variety or strain	Mean (lb.)	Shortest significant ranges[1]
†Y 13	2.80	a	†Y 13	2.63	a
†1252	2.37	b	1483	2.17	ab
†NY 59-400	2.37	b	†NY 59-400	2.09	abc
†ES 24	2.29	b	†1252	2.01	abcd
†Brehm's Solid Red	2.12	bc	†ES 24	1.86	bcde
1483	1.91	bcd	†H 1369	1.61	bcdef
Garden State	1.84	cde	Ark. 60-19-1	1.54	bcdefg
†H 1369	1.79	cdef	Garden State	1.52	cdefgh
†HRS 193	1.73	cdef	†HRS 193	1.46	cdefgh
Kc 146	1.73	cdef	†Brehm's Solid Red	1.43	defgh
Rutgers	1.67	cdefg	Ace-VF	1.39	defgh
Imp. T-2	1.56	defg	Rutgers	1.36	efgh
Kc 109	1.54	defg	Kc 146	1.23	efghi
Y 206	1.50	defg	Imp. T-2	1.18	fghi
Ace-VF	1.39	efg	Y 206	1.18	fghi
Gardener	1.38	efgh	Kc 109	1.14	fghi
Y 112	1.37	efgh	Gardener	.96	ghi
Ark. 60-19-1	1.32	fgh	Y 112	.92	ghi
T 6003	1.22	gh	T 6003	.91	hi
MAT	.91	h	MAT	.68	i
Mean of firm varieties	2.21			1.87	
Mean of soft varieties	1.49			1.46	
General mean and standard error	1.74 ±0.143			1.46 ±0.182	

[1] Means with the same letter are not different from each other at the .05 level of significance.
† Varieties or strains classified as having firm fruits.

fruits with soft flesh, did test in the lower range of firmness. However, the means of several lines were lower than Gardener, but not significantly so. The apparent increase in firmness of the strain Ark. 60-19-1 from 7 to 14 days can not be considered a true effect. The combined mean of the two 7-day samplings was low because the first sample was very low, with a value of 1.01. The mean of the second sample was 1.62, which is larger than the 14-day sample that was harvested at the same time. Although the method can not be considered objective, fruits of Ark. 60-19-1 do feel fairly firm to the touch.

Measurement of pH, total titratable acidity, soluble and total solids, and fruit weight

In all instances, differences between the 21 varieties for the five measurements were highly significant (Table 13). No significant difference was measured between the means of the two 7-day samplings. Highly significant differences were measured between the means of the 7- and the 14-day samplings for the four measurements of quality, but not for fruit

Table 13. — Analysis of Variance of 21 Varieties or Strains Tested for pH, Total Titratable Acidity, Soluble Solids, Total Solids, and Weight of Fruits at Different Sampling and Testing Dates

Source of variation	Degrees of freedom	Mean squares for —				
		pH	Total titratable acidity	Soluble solids	Total solids	Fruit weight
		7 + 7-day samples				
Total	83					
Replications	1	.0107	.00016	.240	.027	2931.13
Sampling dates	1	.2465	.00053	.130	.000	211.85
Error a	1	.1036	.00010	.020	.146	390.01
Varieties	20	.0367**	.02281**	.849**	.833**	7203.90**
Error b	20	.0076	.00062	.025	.069	553.36
Varieties x sampling dates	20	.0056	.00145**	.119*	.077	732.49**
Error c	20	.0046	.00041	.045	.054	223.67
		7 + 14-day samples				
Total	82[1]					
Replications	1	.0629**	.00264*	.000	.298	5801.71**
Varieties	20	.0344**	.02131**	.825**	.849**	5595.36**
Error a	20	.0055	.00055	.051	.132	460.56
Testing dates	1	.8804**	.10240**	1.600**	.670**	427.51
Varieties x testing dates	20	.0032	.00104	.044	.048	86.25
Error b	20[1]	.0059	.00058	.037	.050	110.05
		14-day samples				
Total	40[1]					
Replications	1	.0029	.00323*	.130	.381	3077.15**
Varieties	20	.0146**	.00800**	.320**	.405**	2947.91**
Error	19[1]	.0019	.00041	.044	.105	209.92

[1] One degree of freedom less because of missing subplot value.
* Exceeds .05 level of significance.
** Exceeds .01 level of significance.

weight. The pH increased while total acidity, total solids, and soluble solids decreased with ripening (Tables 14, 15, 16, 17, 18). Varieties did not respond differentially when ripened from 7 to 14 days. However, statistically significant differential responses of varieties were measured in the comparison of the two 7-day samplings for total acidity, soluble solids, and fruit weight. These data clearly indicate the influence seasonal effects have on total acidity, and to a lesser degree, soluble solids. Additional research is needed on the improvement of sampling procedures for these two constituents.

Table 14. — Ranked Varietal Means of pH of Fruits and Shortest Significant Ranges for Two Samplings Harvested at Incipient Coloring and Ripened for 7 Days, and for One Sampling Harvested and Ripened for 14 Days at 65° F.

7+7-day samples			14-day samples		
Variety or strain	Mean	Shortest significant ranges[1]	Variety or strain	Mean	Shortest significant ranges[1]
Garden State....	4.40	a	Garden State....	4.50	a
1252............	4.39	ab	1252............	4.50	a
Rutgers.........	4.34	abc	Rutgers.........	4.45	ab
Y 13...........	4.28	abcd	T 6003..........	4.40	abc
Y 112...........	4.28	abcd	Y 206...........	4.40	abc
T 6003.........	4.25	bcde	MAT...........	4.40	abc
Y 206..........	4.24	cdef	Ace-VF.........	4.40	abc
Gardener.......	4.22	cdef	Y 112...........	4.38	bcd
Imp. T-2.......	4.21	cdef	Gardener........	4.38	bcd
MAT...........	4.20	cdef	Imp. T-2........	4.38	bcd
Kc 109.........	4.19	def	Kc 109..........	4.35	bcd
H 1369.........	4.19	def	H 1369.........	4.35	bcd
Kc 146.........	4.18	def	Kc 146..........	4.35	bcd
Roma..........	4.18	def	Roma...........	4.35	bcd
Brehm's Solid Red	4.16	def	Y 13............	4.32	cd
HRS 193.......	4.15	def	Ark. 60-19-1.....	4.32	cd
ES 24..........	4.15	def	Brehm's Solid Red	4.30	cd
NY 59-400......	4.12	defg	HRS 193........	4.30	cd
Ark. 60-19-1.....	4.11	efg	ES 24...........	4.28	d
Ace-VF.........	4.09	fg	NY 59-400......	4.28	d
†1483...........	4.00	g	†1483............	4.10	e
Mean and standard error......	4.20±0.044			4.36±0.031	

[1] Means with the same letter are not different from each other at the .05 level of significance.
† Classified as having fruits with low pH.

Table 15. — Ranked Varietal Means of Total Titratable Acidity of Fruits and Shortest Significant Ranges for Two Samplings Harvested at Incipient Coloring and Ripened for 7 Days, and for One Sampling Harvested and Ripened for 14 Days at 65° F.

7+7-day samples			14-day samples		
Variety or strain	Mean (gm./100gm.)	Shortest significant ranges[1]	Variety or strain	Mean (gm./100gm.)	Shortest significant ranges[1]
†1483	.690	a	†1483	.610	a
Ark. 60-19-1	.668	a	Ark. 60-19-1	.555	b
NY 59-400	.536	b	NY 59-400	.457	c
Ace-VF	.512	bc	HRS 193	.434	cd
HRS 193	.508	bc	ES 24	.426	cde
Brehm's Solid Red	.508	bc	Brehm's Solid Red	.414	cdef
MAT	.481	cd	Y 13	.413	cdef
ES 24	.477	cd	MAT	.410	cdef
Gardener	.462	de	Gardener	.407	defg
Kc 109	.462	de	Y 112	.404	defg
Y 13	.453	def	Kc 109	.398	defgh
Y 112	.453	def	Ace-VF	.395	defgh
Y 206	.450	defg	Y 206	.383	efgh
1252	.450	defg	H 1369	.380	efgh
T 6003	.448	defg	1252	.377	efgh
Kc 146	.434	efgh	Kc 146	.371	fgh
Rutgers	.434	efgh	Rutgers	.368	fgh
Garden State	.420	fgh	Garden State	.368	fgh
H 1369	.412	fgh	T 6003	.365	fgh
Roma	.409	gh	Imp. T-2	.359	gh
Imp. T-2	.400	h	Roma	.353	h
Mean and standard error	.479±0.0124			.412±0.0143	

[1] Means with the same letter are not different from each other at the .05 level of significance.
† Classified as having fruits with high total titratable acidity.

Table 16. — Ranked Varietal Means of Soluble Solids of Fruits and Shortest Significant Ranges for Two Samplings Harvested at Incipient Coloring and Ripened for 7 Days, and for One Sampling Harvested and Ripened for 14 Days at 65° F.

7+7-day samples			14-day samples		
Variety or strain	Mean (%)	Shortest significant ranges[1]	Variety or strain	Mean (%)	Shortest significant ranges[1]
Ark. 60-19-1	6.80	a	Ark. 60-19-1	6.65	a
HRS 193	6.23	b	Brehm's Solid Red	6.10	b
Brehm's Solid Red	6.15	b	HRS 193	6.03	bc
MAT	5.87	c	NY 59-400	5.90	bcd
1252	5.87	c	MAT	5.83	bcde
1483	5.85	c	Gardener	5.83	bcde
Garden State	5.85	c	1483	5.75	bcdef
Gardener	5.75	cd	Garden State	5.67	cdef
NY 59-400	5.73	cd	1252	5.57	defg
Y 112	5.70	cde	Rutgers	5.57	defg

(Table is concluded on next page)

Table 16. — Concluded

7+7-day samples			14-day samples		
Variety or strain	Mean (%)	Shortest significant ranges[1]	Variety or strain	Mean (%)	Shortest significant ranges[1]
T 6003	5.63	cde	Y 112	5.53	defg
Rutgers	5.57	de	T 6003	5.47	efgh
Kc 109	5.55	de	Kc 109	5.47	efgh
Ace-VF	5.50	de	Ace-VF	5.37	fghi
Kc 146	5.43	ef	Kc 146	5.23	ghi
Y 206	5.27	fg	ES 24	5.13	hi
Y 13	5.25	fg	Roma	5.05	ij
ES 24	5.17	gh	Y 206	5.03	ij
Roma	5.15	gh	Y 13	5.03	ij
H 1369	4.93	hi	H 1369	5.00	ij
Imp. T-2	4.77	i	Imp. T-2	4.75	j
Mean and standard error	5.62±0.079			5.38±0.113	

[1] Means with the same letter are not different from each other at the .05 level of significance.

Table 17. — Ranked Varietal Means of Total Solids of Fruits and Shortest Significant Ranges for Two Samplings Harvested at Incipient Coloring and Ripened for 7 Days, and for One Sampling Harvested and Ripened for 14 Days at 65° F.

7+7-day samples			14-day samples		
Variety or strain	Mean (%)	Shortest significant ranges[1]	Variety or strain	Mean (%)	Shortest significant ranges[1]
Ark. 60-19-1	6.31	a	Ark. 60-19-1	6.00	a
HRS 193	5.69	b	HRS 193	5.62	ab
Brehm's Solid Red	5.69	b	Brehm's Solid Red	5.62	ab
MAT	5.44	bc	MAT	5.25	bc
Garden State	5.44	bc	NY 59-400	5.25	bc
NY 59-400	5.38	bc	Gardener	5.25	bc
Gardener	5.25	cd	T 6003	5.12	bcd
1483	5.25	cd	Garden State	5.00	bcde
†Y 112	5.19	cde	†Y 112	5.00	bcde
Rutgers	5.06	cdef	Rutgers	5.00	bcde
1252	5.06	cdef	1252	4.88	bcde
Ace-VF	5.06	cdef	Kc 109	4.88	bcde
T 6003	5.00	cdef	1483	4.75	cde
Kc 146	5.00	cdef	Ace-VF	4.62	cde
Kc 109	4.88	def	Kc 146	4.62	cde
Roma	4.88	def	Roma	4.62	cde
ES 24	4.75	ef	ES 24	4.62	cde
Y 13	4.75	ef	H 1369	4.62	cde
H 1369	4.62	f	†Y 206	4.38	de
†Y 206	4.62	f	Imp. T-2	4.38	de
Imp. T-2	4.19	g	Y 13	4.25	e
Mean and standard error	5.12±0.131			4.94±0.229	

[1] Means with the same letter are not different from each other at the .05 level of significance.
† Varieties or strains classified as having fruits with high total solids.

Table 18. — Ranked Varietal Means of Fruit Weight and Shortest Significant Ranges for Two Samplings Harvested at Incipient Coloring and Ripened for 7 Days, and for One Sampling Harvested and Ripened for 14 Days at 65° F.

7+7-day samples			14-day samples		
Variety or strain	Mean (gm.)	Shortest significant ranges[1]	Variety or strain	Mean (gm.)	Shortest significant ranges[1]
Kc 146	210.5	a	Imp. T-2	207.9	a
Y 112	208.1	a	Y 112	205.1	a
Garden State	197.4	ab	Brehm's Solid Red	183.6	ab
Imp. T-2	196.0	ab	Kc 146	175.5	abc
Y 206	170.3	bc	ES 24	169.3	bcd
ES 24	168.6	bc	Ace-VF	165.3	bcde
Ace-VF	167.1	bc	Y 206	163.7	bcde
Kc 109	161.2	bc	Garden State	160.1	bcde
1252	155.3	cd	MAT	141.9	cdef
Brehm's Solid Red	151.6	cd	1252	141.7	cdef
MAT	142.9	cde	Kc 109	140.3	defg
Rutgers	138.4	cde	Rutgers	139.3	defg
NY 59-400	131.6	cdef	H 1369	133.6	efgh
Gardener	119.6	defg	NY 59-400	115.2	fghi
Y 13	116.2	defgh	Gardener	112.8	fghi
H 1369	111.3	efgh	HRS 193	110.5	fghi
HRS 193	106.7	efgh	1483	107.0	ghij
1483	98.9	fghi	Ark. 60-19-1	99.9	hij
Ark. 60-19-1	86.4	ghi	Y 13	97.9	ij
T 6003	79.5	hi	T 6003	77.1	j
Roma	65.5	i	Roma	74.1	j
Mean and standard error	142.1 ± 11.76			139.1 ± 10.24	

[1] Means with the same letter are not different from each other at the .05 level of significance.

pH and total titratable acidity. As expected, the Illinois high-acid line 1483 had significantly lower pH and higher acidity than any other line tested, with the exception of Ark. 60-19-1, at the 7-day sampling dates for total acidity (Tables 14 and 15). Ark. 60-19-1 exhibited a surprisingly high level of acidity, not having been selected for this character. Several other strains including NY 59-400, HRS 193, Brehm's Solid Red, and ES 24 merit consideration as sources of variability for lower pH and higher acidity in future breeding research. The variety Ace-VF appeared to have a good level of acidity and low pH in the 7-day samples, but the levels did not hold up during ripening to 14 days. It is of interest to note that most of the strains having the highest degree of flesh firmness, with the exception of the two high-pigment lines, also have the highest levels of acidity and the lowest pH. Research is needed to determine if any causal relationship exists between acidity and firmness in tomato fruits.

Soluble and total solids. The relative rankings of the varieties were approximately the same for both soluble and total solids. The strain Ark. 60-19-1 was outstandingly high in both measurements. Brehm's Solid Red and HRS 193 also tested high. The two lines Y 112 and Y 206 respectively had only average and below average levels of total solids. The soluble solids readings on these two lines were similar to that of total solids. It may be concluded that Y 112 and Y 206 do not have genetic factors for high solids content. Several varieties were consistently low in solids. It would appear that progress could be made in breeding for higher levels of solids than now exist in the standard varieties.

Fruit weight. The data in Table 18 give some indication of the variation in fruit weight among the varieties and strains tested. More useful estimates of fruit weight undoubtedly could be obtained by other methods since the samples taken were selected for uniformity, which probably introduced biases of an unpredictable nature.

Holding capacity of fruits on the vine

Significant varietal differences in the holding capacity of fruits on the vine are indicated in the preliminary results (Table 19). It is obvious that holding capacity or what might be termed "field or vine storage" of fruits depends in part on the extent of firmness and the relative resistance to cracking of the fruit. Garden State typifies what can be expected of a variety lacking both firmness and resistance to total cracking. It is not possible to tell from these data whether firmness or crack resistance is the more important factor. It is obvious that if fruits do not crack the probability of loss through decay is decreased. HRS 193 ranked at the top even though it has only average firmness and potentially high susceptibility to total cracking. Actually this strain has a high level of resistance to radial cracking, and the fruits were relatively free of cracks in the field. Severe cracking in the field was only noted on Garden State and 1252. The relative importance of firmness is illustrated by the below average performance of Kc 109 and Kc 146, both having a high level of crack resistance, but only average level of firmness. It appears that the firmness of 1252 tended to partially offset the high susceptibility to cracking in this line.

The classification of defects on culls gives an indication of the nature of the loss. Loss of fruits by sunburning indicates relatively poor foliage cover, as was observed on the varieties Roma, Brehm's Solid Red, Kc 109, Kc 146, and ES 24. Of the varieties with inadequate foliage, only Brehm's Solid Red did not have a rather high amount of sunburned fruits in the tagged samples. Loss by sunburning would appear to have little relationship to the other forms of loss. On the other hand, excessively heavy foliage would tend to favor an increase in ground rot.

Table 19. — Holding Ability of Tomato Fruits Tagged at Incipient Coloring and Ripened on the Vine 14 Days Before Harvest

Variety	No. of fruits	Total wt. of fruits (lb.)	Mean wt. of fruits (lb.)	Marketable fruits (%)		Defects on culls (number of fruits)				Cracking[1]		Firmness[1]	
				No.	Wt.	Sun-burn	Ground rot	Decay at cracks	Total decay	Mean ($\sqrt{T}$)	L.S.R.	Mean (lb.)	L.S.R.
HRS 193.	43	11.1	.26	90.7	89.2	1	3	0	1	4.26	c	1.73	cdef
ES 24.	45	15.0	.33	80.0	80.0	6	6	0	0	3.19	g	2.29	b
Brehm's Solid Red. . .	28	10.0	.36	78.6	75.0	0	0	6	0	3.53	ef	2.12	bc
1252.	18	7.0	.39	77.8	80.0	0	0	4	0	4.76	b	2.37	b
Roma.	63	10.6	.17	69.8	70.8	9	0	0	14	1.67	i	. . . .	. . . .
Kc 146.	39	16.5	.42	69.2	66.7	4	7	1	0	3.27	fg	1.73	cdef
Kc 109.	46	16.1	.35	60.9	63.4	9	0	2	7	2.46	h	1.54	defg
Garden State.	19	8.6	.45	36.8	36.0	1	3	10	0	4.19	c	1.84	cde

[1] Means and least significant ranges (L.S.R.) from data on total cracking (Table 10) and firmness on 7 + 7-day samples (Table 12). Means with the same letter are not different from each other at the .05 level of significance.

Considerable additional research is needed to determine the environmental and plant factors involved in the holding capacity of fruits in the field. The importance of this characteristic in a variety adapted to efficient mechanical harvesting can not be overemphasized. Although other factors may be equally important, significant increases in holding capacity should be realized by increasing the level of firmness and resistance to cracking. Even with existing knowledge and breeding material, it would appear that progress can be made in breeding for varieties that will hold fruits in a marketable condition for longer periods of time than is now possible with existing commercial varieties.

Factors affecting breakage induced by dropping fruit

To study the effect of height of drop, field-ripe fruits of the variety Kc 146 were dropped from heights of 1, 1½, and 2 feet (Tables 20 and 21). Thirty fruits were used in each sample and a firmness test was run on 15 fruits of a comparable sample. The increase in breakage was essentially linear with increased height. The fruits that did not break at the first drop were then dropped from the same height repeatedly until breakage was induced. The number of times dropped was recorded and presented as a frequency distribution in Table 21. From the standpoint of mechanical harvesting, these data indicate that drops within the machine of more than one foot, or more than two or three drops at one foot would appear to be excessive to fully ripe fruit.

As expected, stage of maturity greatly influences the extent of breakage induced by dropping. It is important to note that maximum quality, as indicated by the extent of color development, is not reached until the fruits are fully mature. Since severe injury occurs when fully ripe fruits are dropped, consideration must be given to the engineering design of the mechanical harvesters, and the improvement of varieties able to withstand the handling.

Smaller fruits appear to be less susceptible to breakage than larger fruits. This would indicate that varieties with smaller fruits would be best adapted to mechanical harvesting. Green and otherwise immature fruits create a sorting problem when fruits are harvested mechanically. For this reason it is commonly believed that the fruit size of a variety adapted to mechanical harvesting should be relatively large. If the sorting problem could be minimized by some means of concentration of fruit set and maturity, varieties with smaller fruits should perform more satisfactorily than those with larger.

Time of day apparently has an influence on the extent of induced fruit breakage. Nearly twice as many fruits were damaged in the morning. The difference may be explained in part by the relative content of

Table 20. — Effect of Height of Drop, Stage of Maturity, Size of Fruit, Time of Day, Moisture Content and Temperature, and Varietal Differences on the Extent of Breakage of Tomato Fruits Induced by Dropping

Type of sample tested and variety	Mean weight of fruits (lb.)	Total carotenoid pigments (mgm./100gm.)	Firmness		Breakage after dropping		
			Number of fruits tested	Mean and standard error (lb.)	Height of drop (ft.)	Number of fruits tested	Fruits cracked (%)
Height of drop (Kc 146)							
1 foot			15	1.52 ± 0.143	1	30	10.0
1½ feet			..	.....	1½	30	40.0
2 feet			..	.....	2	30	70.0
Stage of maturity (Kc 146)							
Light pink	.35	3.01	10	4.58 ± 0.175	2	20	10.0
Dark pink	.36	5.13	10	3.46 ± 0.188	2	25	24.0
Fully colored, firm	.39	6.80	10	2.70 ± 0.101	2	30	67.0
Field ripe	.40	9.59	10	1.68 ± 0.228	2	30	100.0
Size of fruit (Kc 109)							
Small	.30				2	45	48.9
Medium	.45				2	35	68.6
Large	.64				2	25	76.0
Time of day (Kc 146)							
Morning					2½	30	75.0
Afternoon					2½	67	47.8
Moisture and temperature (Kc 146)							
Untreated			23	1.82 ± 0.105	1½	33	45.5
Infiltrated with cool water 21° C.			..	.....	1½	53	45.3
Infiltrated with warm water 35° C.			..	.....	1½	67	40.3
Varietal differences							
NY 59-400	.34	9.59	12	2.64 ± 0.255	2½	35	20.0
Gardener	.32	8.00	12	.99 ± 0.192	2½	37	97.3
Roma[1]					2	26	19.2
Roma[1]					2½	23	34.8
Roma[2]					2	24	41.7
Roma[2]					2½	40	45.0
Sticky peel (*pe*)					2½	55	50.9
Ark. 60-19-1					2½	43	55.8
Y 13					2½	58	60.3
HRS 193					2½	39	66.7
ES 24					2½	35	74.3
Kc 109					2½	36	91.7
Garden State					2½	44	97.7
Kc 146					2½	45	97.8

[1] Dropped on side.
[2] Dropped on stylar end.

Table 21. — Frequency Distribution of Number of 1-, 1½-, and 2-foot Drops Necessary to Induce Breakage in Field-Ripe Kc 146 Tomato Fruits

Number of times dropped to induce breakage	Height of drop					
	1 foot		1½ feet		2 feet	
	Number of fruits cracked	Accumulated percentage of fruits cracked	Number of fruits cracked	Accumulated percentage of fruits cracked	Number of fruits cracked	Accumulated percentage of fruits cracked
1	3	10	12	40	21	70
2	3	20	10	73	8	97
3	6	40	3	83	0	97
4	8	67	4	97	0	97
5	1	70	1	100	0	97
6	3	80	0	..	1	100
7–11	4	93	0	..	0	..
12–16	2	100	0	..	0	..
Number of fruits tested	30		30		30	
Mean and standard error of number of drops to induce breakage	5.1 ±0.68		2.1 ±0.21		1.4 ±0.14	

water in the fruits at the two periods of time. The fruits in the morning would be expected to be more turgid, and therefore more susceptible to breakage by dropping. The results of the experiment in which the moisture content of fruits was increased by infiltration with cool and warm water are inconclusive. Infiltration with cool water had no apparent effect, but a slight reduction in breakage was observed in those fruits treated with warm water. If the effect of temperature is a true one, part of the reduction in breakage in the afternoon sample may be due to higher temperatures of the fruits. It is conceivable that elasticity of cells and epidermis may be increased at higher temperatures, thus affording a certain amount of protection to the fruits. Additional research is needed on these factors since the height of the drops for the infiltration study was only 1½ feet. More conclusive results undoubtedly would have been obtained if the drops had been at a greater height.

Obvious differences in extent of breakage were measured in the comparison of the 11 varieties. NY 59-400 performed outstandingly well in comparison with all the other lines. Undoubtedly the high levels of crack resistance and firmness in this strain are major factors in its resistance to breakage. The performance of NY 59-400 is striking when compared directly to Gardener, which has only average resistance to cracking, relatively soft flesh, and essentially the same fruit size.

Apparently resistance to cracking is not sufficient in itself to confer resistance to breakage since Kc 109 and Kc 146 performed similarly to Garden State. The higher level of crack resistance in Kc 109 may account for its slightly better performance compared to that of Kc 146. The lines Ark. 60-19-1, HRS 193, and ES 24, which have some degree of firmness and resistance to cracking, and Y 13, which has a good level of firmness but high susceptibility to cracking, gave intermediate performances in the test. Part of the difference may be attributed to size since Ark. 60-19-1, HRS 193, and Y 13 tend to have smaller fruits than the average variety. ES 24, similar to Kc 146, however, has larger than average fruit. The sticky peel line which has extremely soft flesh also gave an intermediate performance. Further research with this material is needed to determine if the sticky peel character has any commercial value.

Roma, having a small fruit averaging approximately 0.15 pound, gave a slightly better performance than the intermediate varieties. Size and shape and internal structure of the fruits undoubtedly are important factors in the apparent resistance of this variety. Considerably more breakage was obtained when fruits were dropped on the stylar end than on the side. Only the very ripest fruits cracked when dropped on the side at the 2-foot drop.

External cracking of the fruits, of course, is not the only possible source of damage to a fruit after having been dropped. Bruising and subsequent enzymatic breakdown and development of off flavors in the fruits may be a serious problem and require further investigation. It may be concluded that progress should be possible in breeding varieties that will withstand handling injury. The strain NY 59-400 should serve as a valuable source of resistance in future breeding research.

Summary of varieties or strains recommended for additional research

The varieties or strains that gave superior performance for the various fruit characteristics evaluated in the experiment are summarized in Table 22. No single variety ranked at the top for all categories, but NY 59-400 was included in nine out of the total fourteen. Roma, Ark. 60-19-1, and HRS 193 also ranked high on the list. It would appear that considerable improvement could be made by incorporating the desirable characteristics of these lines into commercially adapted varieties. However, the efficient incorporation of these sources of variation depends to a large degree on the utilization of adequate sampling and testing procedures. Considerable additional research is needed to improve sampling and testing techniques adapted to segregating populations.

Table 22. — Summary of Varieties or Strains That May Serve as Future Sources of Variability in Plant Breeding Programs for the Improvement of Tomato Fruit Quality

Fruit characteristics	Varieties or strains				
Color					
High total pigments	1252	Y 13	Ark. 60-19-1	HRS 193	
High carotene	Y 13	1252	ES 24		
Low carotene	NY 59-400	Roma			
High T/C ratio	NY 59-400	Roma	Ark. 60-19-1	HRS 193	
High Hunter a/b ratio	1252	Roma	HRS 193	NY 59-400	
Crack resistance					
Radial	Roma	HRS 193	NY 59-400	Imp. T-2	Kc 109
Concentric	Ark. 60-19-1	NY 59-400	Garden State	Roma	Kc 109
Total	Roma	NY 59-400	Ark. 60-19-1	Kc 109	
Firmness	Y 13	1252	NY 59-400	ES 24	1483
Resistance to breakage when dropped	NY 59-400	Roma			
pH	1483				
Total titratable acidity	1483	Ark. 60-19-1	NY 59-400		
Soluble solids	Ark. 60-19-1	HRS 193	Brehm's Solid Red		
Total solids	Ark. 60-19-1	HRS 193	Brehm's Solid Red		

SUMMARY

Twenty-one varieties or strains of tomatoes were evaluated and characterized for color, crack resistance, firmness of flesh, pH, total titratable acidity, soluble solids, total solids, and fruit weight in a replicated experiment. All samples were selected at incipient coloring, and except for samples tested for resistance to cracking, were ripened at $65° \pm 1.5°$ F. for 7 and 14 days before analysis. In addition, tests of an exploratory nature were conducted on a portion of the varieties to determine the holding capacity of fruits in the field, and resistance to breakage of fruits when dropped.

Highly significant varietal differences were measured in all of the constituents of quality evaluated. No differences were measured between the two 7-day samplings, but highly significant differences were found between the 7- and 14-day testing dates for all measurements except fruit weight. In most instances varieties did not respond differentially at the different sampling and testing dates. Therefore, one sampling date may be sufficient for an adequate determination of relative performance for most of the characteristics if adequate sampling techniques are employed.

The strain NY 59-400 gave the best overall performance, ranking high in color, crack resistance, firmness, resistance to breakage when dropped, and total titratable acidity. The Illinois high-pigment line 1252 ranked high in total carotenoid pigments, carotene, Hunter a/b ratio, and firmness. The other high-pigment line Y 13 also ranked high in total pigments, carotene, and firmness. Roma ranked high in color, crack resistance, and resistance to breakage when dropped. The line Ark. 60-19-1

had good color, crack resistance, high total titratable acidity, and high soluble and total solids. The Illinois high-acid line 1483 had the lowest pH and highest total titratable acidity, and a good level of flesh firmness. Kc 109 also ranked near the top in resistance to cracking. These varieties and strains should serve as good sources of variation for future tomato breeding research. Although considerable additional research is needed on the improvement of sampling and testing procedures, those used in this study would be feasible for use in a practical breeding program.

LITERATURE CITED

1. Anderson, R. E. Factors affecting the acidic constituents of the tomato. Ph.D. thesis, Univ. of Ill. 63 p. 1957.
2. Duncan, D. B. Multiple range and multiple F tests. Biometrics **11**:1-42. 1955.
3. Foda, Y. H. Pectic changes during ripening as related to flesh firmness in the tomato. Ph.D. thesis, Univ. of Ill. 66 p. 1957.
4. Garrett, A. W., Desrosier, N. W., Kuhn, G. D., and Fields, M. L. Evaluation of instruments to measure firmness of tomatoes. Food Tech. **14**:562-564. 1960.
5. Harter, H. L. Critical values for Duncan's new multiple range test. Biometrics **16**:671-685. 1960.
6. Hepler, R. W. The measurement and inheritance of resistance to fruit cracking in the tomato. Ph.D. thesis, Univ. of Ill. 83 p. 1961.
7. McCollum, J. P. Effect of sunlight exposure on the quality constituents of tomato fruits. Proc. Amer. Soc. Hort. Sci. **48**:413-416. 1946.
8. ———— A rapid method for determining total carotenoids and carotene in tomatoes. Proc. Amer. Soc. Hort. Sci. **61**:431-433. 1953.
9. ———— Effects of light on the formation of carotenoids in tomato fruits. Food Res. **19**:182-189. 1954.
10. ———— Distribution of carotenoids in the tomato. Food Res. **20**:55-59. 1955.
11. ———— Sampling tomato fruits for composition studies. Proc. Amer. Soc. Hort. Sci. **68**:587-595. 1956.
12. Thompson, A. E. A comparison of fruit quality constituents of normal and high pigment tomatoes. Proc. Amer. Soc. Hort. Sci. **78**:464-473. 1961.
13. Wann, E. V., and McFerran, J. Studies of the inheritance of red color in fruits of *Lycopersicon pimpinellifolium* Mill. Proc. Amer. Soc. Hort. Sci. **76**:524-529. 1960.

4M—4-62—76287